

MASTER

COMPUTER SOFTWARE FOR PLANNING AND DESIGN OF COMMUNITY ENERGY SYSTEMS

by

Veronika A. Rable, James M. Calm and John J. Roberts

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared for

The Joint National Meeting of the
Operations Research Society of America and

The Institute of Management Sciences

Los Angeles, California

November 13-15, 1978

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *EB*



U of C-AUA-USDOE

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Operated under Contract W-31-109-Eng-38 for the
U. S. DEPARTMENT OF ENERGY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) between the U. S. Department of Energy, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

MEMBERS OF ARGONNE UNIVERSITIES ASSOCIATION

The University of Arizona	Kansas State University	The Ohio State University
Carnegie-Mellon University	The University of Kansas	Ohio University
Case Western Reserve University	Loyola University	The Pennsylvania State University
The University of Chicago	Marquette University	Purdue University
University of Cincinnati	Michigan State University	Saint Louis University
Illinois Institute of Technology	The University of Michigan	Southern Illinois University
University of Illinois	University of Minnesota	The University of Texas at Austin
Indiana University	University of Missouri	Washington University
Iowa State University	Northwestern University	Wayne State University
The University of Iowa	University of Notre Dame	The University of Wisconsin

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights. Mention of commercial products, their manufacturers, or their suppliers in this publication does not imply or connote approval or disapproval of the product by Argonne National Laboratory or the U. S. Department of Energy.

Computer Software for Planning and Design
of
Community Energy Systems

Veronika A. Rabl, James M. Calm, and John J. Roberts*
Energy and Environmental Systems Division
Argonne National Laboratory

ABSTRACT

Simulation and optimization procedures for community energy systems are presented. Community systems have been recognized as offering energy conserving alternative methods of meeting the energy service needs of communities. This paper discusses the Integrated Community Energy Systems (ICES) approach, explores the need for sophisticated analytical methods for ICES planning and design, and presents a software series developed or under development to meet these needs.

INTRODUCTION

The concept of Integrated Community Energy Systems (ICES) evolved within a search for novel, energy conserving approaches to the energy supply problem. It is based on a belief that when the consumer service area is not confined to a single building, a number of options, generally not available to single buildings, can be taken advantage of to achieve a better utilization of resource energy. In particular:

- economies of scale by servicing a larger demand;
- better load factors as a consequence of diversity, or combining different demand patterns;
- use of byproduct and/or otherwise wasted energy forms;
- reduction in the costs of system reliability and availability; and
- improved latitude in selecting the service areas and corresponding supply systems.

ICES are being considered for applications where all or part of energy

*Office of the Director, Argonne
National Laboratory

related services are supplied to communities as large as several hundred megawatts of equivalent electric demand. The target communities thus may be as different as a municipal or suburban business district, a farm community, a university campus, an office complex, or a multi-zoned planned unit development. The services considered reflect the diversity of the customers; they may range from traditional electrical supply and environmental conditioning through transportation, communication, snow removal, and trash collection. In general, not all services need be supplied by the integrated energy system; for example, in some cases it will be neither energy conserving nor economical to generate electricity. The system concepts include total and selective energy, cogeneration, cascading, district heating and cooling systems, and may incorporate a number of new technologies under development for the near term and future markets, such as fuel cells, improved turbines, advanced power cycles, solar, and storage options.

The emphasis throughout the ICES approach is on integration, or achievement of an improved match between the community's energy requirements, as dictated by its functions and service

needs, and the energy systems that supply it, as well as on integration within the supply system itself through energy cascading and cogeneration.

THE ROLE OF ANALYTICAL METHODS

It is precisely the reasons that indicate the advantages of the ICES approach that suggest the need for detailed systems analyses. To conserve energy, it is important that the systems which supply, convert, and utilize energy operate at, or at least near, peak performance to avoid penalties of inefficient operation. Recognizing the complex interactions and operating conditions of some ICES, particularly as the relative proportions of respective outputs vary due to external factors, a design based on peak demand for any single service could easily prove inefficient on an annual basis. The determination of the optimal number and size of system components and efficient operating and storage utilization strategies as well as the analysis of system reliability and availability require sophisticated methods. While it is obviously desirable that the analyses themselves not be encumbered by unnecessary complexity, or, for that matter, by artificial precision beyond input information, the number of parameters to be considered even for a relatively simple ICES cannot be addressed with crude approximations.

Detailed analysis of ICES is far more important than for conventional systems. In the conventional systems approach, many small systems are mass produced and their performance and application procedures become optimized through experience and market conditions. For the ICES approach, each system is tailored for the specific needs, resources, lifestyles, composition, economics, and a myriad of other factors unique to the community being served. The nature of the system is such that prototype construction and refinement is impractical. In place of a physical prototype, the engineer must rely upon a mathematical model. The analytical methods need, therefore, not only be sophisticated with regard to analytical approaches, but also with regard to the input and output data formats to enable the user to efficiently and correctly utilize them.

An additional justification for sophisticated analyses is the impact of failure, either economic or physical, of the ICES on the community. Unless performance and resulting economics have been accurately predicted, the ICES will fail as a municipal or private enterprise undertaking. In that event, the community which has installed building systems dependent upon the community system will be left with major financial burdens. In the event of a physical failure, the community would be left without the necessary energy services. But again, it is important to recognize that the inherent reliability of critical components within an ICES will, with proper design, afford superior reliability and availability to conventional systems.

The secondary benefits of advanced analytical approaches include the potential for parametric analyses of the sensitivity of ICES to uncertain parameters. For example, information available about future interest and escalation rates is quite imprecise. Similarly, future energy service demands of a community, dependent upon socioeconomic, climatic, community growth, and similar factors, cannot be accurately forecast. Using automated simulation and optimization methods, the impact of these parameters on the ICES economics and performance can be readily determined. One is, then, in a better position to design an ICES for an acceptable level of performance for reasonably anticipated eventualities rather than an optimal design at the edge of a precipice. In addition, the simulation methods also allow the establishment of an operating benchmark with which to compare actual performance. With this approach, one can determine whether a system and its components are performing at an acceptable level; an analogous function in conventional systems is provided by comparison with statistical data.

SOFTWARE DEVELOPMENT APPROACH

Since, as explained above, ICES respond to a number of different service and/or energy requirements simultaneously, the overall energy conservation and economic potentials of the system are more critically dependent on the match between the community demand and the supply system performance characteristics. For example, if the community

determinants dictate a specific ratio of electrical and thermal energy supply, the best overall performance is obtained when the supply system operates at or near its peak efficiency at this particular ratio of its outputs. Theoretically, the matching process should consider varying both the system concept and certain aspects of the community design. However, because of practical considerations and for the purpose of the analytical methods development, it is advantageous to consider the basic community structure as fixed and concentrate the effort on the analysis of the resultant demand and on the supply system. While this approach does not automatically select any particular community design, it still provides the means of evaluating the effects of alternative community compositions, structures, densities, etc., on the overall system performance.

This philosophy results in a modeling approach to ICES which addresses the questions of supply system and demand computations separately. The energy supply system portion of the problem can be further decomposed into three parts: the central system, transmission/distribution, and end-use (in-building) conversion. However, since these three aspects appear to be relatively tightly linked, and cannot be easily separated arbitrarily, an overall model can be used to solve for the major parameters on their interfaces, with the subsystems subsequently addressed in more detailed analyses.

The ICES application places a number of additional requirements on the models. The methods have to be sufficiently flexible to apply to a large variety of system configurations, communities, climatic and economic factors; must include the possibility of service areas differing for different services and commodities being bought or sold to and from entities outside of the community itself; and must calculate and incorporate temporal variations of the demands, rather than be limited to peak demand or annual consumption. Finally, the methods have to rely on input and output terms familiar to their users and be efficient, both in terms of effort and computer time requirements, so as to offer a feasible cost effective alternative to less accurate hand calculations.

The anticipated role of computer programs in an ICES design process is

shown in Figure 1. The figure explicitly incorporates two computer programs, OASIS-I and OASIS-II (Optimization and Simulation of Integrated Systems), which are presently under development and address the supply system. The OASIS-I program is designed to simulate and optimize the operation of the central plant, while the OASIS-II code is concerned with the system as a whole, from the central plant through the distribution and transmission to end-use conversion. This latter program serves to decompose the problem so that other, more detailed models can be used to analyze the ICES subsystems.

The OASIS-I computer program⁽¹⁾ provides a detailed representation of the processes and operating conditions in the central plant. Even though the code is mainly intended to simulate the central plant performance, including the unique, generally non-linear, equipment characteristics, as well as variables associated with the energy

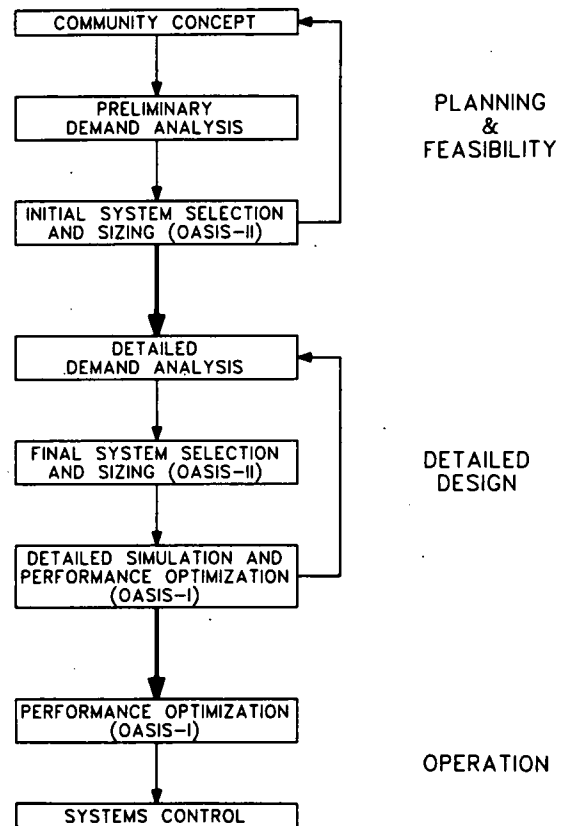


Fig. 1 Computer assisted ICES design

and materials flow through the plant. It contains a network-search, heuristic optimization algorithm designed to select a plant operation strategy which minimizes either energy usage or operating and maintenance costs. The program contains a library of typical equipment performance data as well as numerous default options so as to ease the input for occasional users. In the input, the user specifies the the plant configuration, equipment capacities, and the energy transfer media, and provides the profiles of energy requirements necessary to supply the community's needs. Optional input includes economic data, if economic analysis is desired, and plant operating objectives, if they are to be used instead of those selected by the optimization algorithm. The program then simulates, on a quasi-steady state basis, generally in hourly increments, the response of the plant to the loads. In the optimization mode, it schedules equipment operation, charging or discharging of storage, and, if appropriate, selling of plant products or buying energy forms to directly satisfy the demand.

OASIS-II is a mixed integer linear optimization program⁽²⁾ with the objective function being - at the user's choice - either system efficiency or annual cost. The input into the program consists of service demand profiles (e.g. heating, cooling, lighting), selection of end-use equipment options (e.g. hot water, steam, heat pumps, and/or furnaces for heating), general transmission and distribution system layouts, and the description of the most general acceptable central plant configuration. The user specifies a list of commercially or otherwise available capacities for equipment/processes considered for the plant, as well as economic information and other appropriate constraints on the system selection and performance. Based on the input, supplemented with data stored in equipment performance libraries, the OASIS-II program selects the energy forms to be distributed, the corresponding service areas, and the end-use conversion equipment to supply the services. It sizes the transmission and distribution system mains and selects and sizes the equipment in the central plant. If direct sales and/or purchases were specified as an option, the program output indicates when and how much of the commodity should be bought or sold.

An approach to community energy analysis is also under development. Even though a number of models^(3,4) exist for individual building energy calculations, practical considerations make a building-by-building analysis of a community infeasible, especially considering the large number of parameters required to carry out such calculations. In most cases, either the information does not exist or the effort associated with collecting it would be prohibitive. The model, therefore, must be based on information readily available and, depending on the calculational method selected, the remaining information may have to be generated by statistical means. Moreover, even if building-by-building analyses were feasible, it is not obvious how the addition of the temporal demands could be carried out. The problem arises because presently available building energy programs require deterministic input even for processes that are stochastic in nature, as evidenced by diversity. This factor cannot be neglected when building demands are combined into a community demand. Another consideration to be resolved prior to selecting a particular calculational procedure is the measure of accuracy. Most models are being evaluated in terms of annual consumption while it appears that for ICES the coincidence or the ratio of different types of demands may be a far more significant parameter. A systematic approach to solving these and other related issues is presently under development.

As an initial phase of modeling of transmission/distribution systems, a survey and evaluation is being conducted of existing computer programs in the area of thermal distribution systems. The spectrum of interest ranges from computer programs intended for preliminary economic analyses to those that address engineering design aspects, such as system layout and sizing, through detailed system simulation.

CONCLUSION

Historically, new technologies require from 20 to 30 years between proof of concept and broad acceptance in the market place. In view of energy resource forecasts and the undesirable impact of inefficient resource

consumption (e.g. thermal pollution), analytical methods provide the proving ground and the opportunity for testing proposed variations on a much quicker basis than actual construction. Analytical methods, therefore, offer an opportunity for accelerated commercialization of energy conserving approaches.

It is believed that, when completed, the software series described above will represent a significant step towards providing efficient and cost effective tools for ICES design. The two OASIS programs are undergoing testing at present; it is estimated that they will become publically available towards the end of 1979.

ACKNOWLEDGEMENT

The work described in this paper is sponsored by the Community Systems Branch, Division of Buildings and Community Systems, Office of Conservation and Solar Applications, Department of Energy.

REFERENCES

1. V.A.Rabl, Z.O.Cumali, P.K.Davis, and A.Ulkucu, "OASIS - A Computer Program for Simulation and Optimization of Central Plant Performance", Proceedings of the International Conference on Energy Use Management, Tucson, Arizona, October 1977.
2. P.Nanda, P.Dormont, D.E.Cullen, and M.Gordon, "Optimal Design and Operation of Integrated Energy Systems", presented at the 13th Intersociety Energy Conversion Engineering Conference, San Diego, California, August 1978.
3. "Bibliography on Available Computer Programs in the General Area of Heating, Refrigeration, Air Conditioning and Ventilating", American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., October 1975.
4. W.L.Carroll and J.R.Schaeffgen, "A Review of Computer Software Applicable to the MIUS Program", NBS report NBSIR 77-1307, October 1977.